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ARMY MEDICAL NUTRITION LABORATORY

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**INDIRECT CALORIMETRY BY NEW
TECHNIQUES:**

A DESCRIPTION AND EVALUATION

REPORT 146

7 DEC 1954

**AN INSTALLATION
UNDER THE SURGEON GENERAL
DEPARTMENT OF THE ARMY**

9937 TU
MEDICAL NUTRITION LABORATORY
United States Army
Fitzsimons Army Hospital
Denver 8, Colorado

Report No. 146

7 December 1954

Report of

INDIRECT CALORIMETRY BY NEW TECHNIQUES:

A DESCRIPTION AND EVALUATION

by

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7 December 1954

INDIRECT CALORIMETRY BY NEW TECHNIQUES:
A DESCRIPTION AND EVALUATION

OBJECT:

To assimilate into the methods of indirect calorimetry recently developed apparatus and techniques; to evaluate the accuracy of the resultant method.

SUMMARY AND CONCLUSIONS:

1. The Müller-Franz portable respiratory gas meter, Pauling oxygen analyzer, and Weir formulation of energy metabolism calculations are described as components of a technique for human indirect calorimetry.
2. The errors encountered with these methods are described and evaluated.
3. The method evolved gives results in good agreement with the more laborious older techniques of indirect calorimetry.

RECOMMENDATIONS:

The findings indicate that the incorporation of recently developed techniques into the methods of indirect calorimetry provides a more convenient method with accuracy comparable to older methods. The validation and development of the techniques should be pursued with the subsequent aim of measuring energy expenditure in military occupations.

APPROVED:

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INTRODUCTION

The recent appearance of convenient and continually improving methods of indirect calorimetry has permitted studies of human energy expenditure to be undertaken on an expanded scale inside and outside the laboratory (1). Formerly, the estimation of energy expenditure during work has been largely restricted to the laboratory situation because the use of the Douglas bag and Haldane gas analyzer has been awkward for the subject and time consuming in the laboratory.

A number of these new techniques have been combined into a more convenient method of indirect calorimetry. Müller and Franz at the Max Planck Institute for Work Physiology, Dortmund, have developed a combined portable dry gas meter and fraction sample collector to be employed in the place of the Douglas bag (2). Since Weir has shown the metabolic rate to be essentially a function of the pulmonary ventilation and oxygen content of expired air, the metabolic rate may be calculated after measurement of these two quantities (3). The predominant paramagnetism of oxygen in the normal air gas mixture has been utilized to measure the oxygen concentration of expired air by the Pauling oxygen analyzer (4).

The present paper describes and evaluates these newer techniques as applied to indirect calorimetry. All the following reported studies have been performed at Denver, Colorado, at an altitude of 1 mile above sea level.

DESCRIPTION OF EQUIPMENT AND METHODS

Respiratory Gas Meter.

The Müller-Franz meter* (Figure I) consists of a dry gas meter for measuring the total volume of expired air, coupled to an aliquoting device which continuously removes a portion (0.3 or 0.6%) of the total expired air to an aliquot collection bladder for later analysis (2). A thermometer is enclosed in the metal meter box. The box (20.2 cm. wide, 27.4 cm. high, and 11.2 cm. deep) enclosing the meter and aliquoting device is strapped to the back or front of the chest of the subject by an adjustable harness (Figures II and III).

In addition to being worn the meter may conveniently be set at the side of the subject on a table, chair, or the floor. It is also possible for another person to carry the meter which is connected to the subject by an extended piece of tubing. The usual metal Douglas respiratory valve for collecting the expired air at the mouth is replaced by a plastic valve weighing about 40 grams with a dead space of 32-41 ml. when the rubber mouthpiece is attached. The minimum inside diameter of the respiratory valve is 1.8 cm. at the mouth piece tube. The rubber mouthpieces have flanges which may be bitten upon to secure the mouthpiece and valve during violent exercise. The expired air is conducted from the valve by a flexible rubber tubing, with an inside diameter of 2.5 cm., passing over the subject's shoulder to the

*Zentral-Workstatt Gottinger, Bunjenstrasse 10, Gottinger Germany

meter on his back. The total weight of the meter plus harness, tubing, aliquot bladder, mouthpiece, valve, and nose clip is 3.6 kilos (8 pounds). A 100-liter Douglas bag with a three-way valve, mouthpiece, respiratory valve and tubing, but no harness, weighs 2.9 kilos (6.5 pounds).

Several minor modifications were made in the meter with the accumulation of experience. The original harness was replaced by a complete harness from which the meter was suspended and which held the meter close to the body, minimizing its movement during running and bending forward. The tube from the respiratory valve to the meter was secured by means of a rubber band and clamp to the meter harness at the top of the shoulder strap to insure enough length for free movement of the head and to prevent the tube from flailing during violent exercise. This had to be individually adjusted for each subject. With such precautions it has not been necessary to anchor the valve and mouthpiece with either a strap about the head or a modified face mask. The lever of the three-way valve controlling the metering and sample collection was replaced by a round knob because the protruding lever was easily pushed out of position by clothing and equipment brushing against it. The mica leaflets of the respiratory valve were replaced by similar discs of Polystyrene B sheet, 0.005 inches thick, which while as inert as mica, is in addition, shatter resistant and easy to fashion. The calibration of the meter thermometer was checked and a correction applied to all readings when necessary. A series of adjustments were made to the meter and aliquot pump mechanism in order to reduce the drag of the aliquot device upon the meter. The easily exposed portions of the meter and pump mechanism were cleaned with acetone to remove all heavy lubricants and then oiled at 16 points with motor oil SAE 20. The selector for the aliquot fraction size was permanently set for an aliquot of 0.3% although the actual delivery was only 0.2%. The disc plates of the rotary valve for the aliquot pump were adjusted to the minimum spring force necessary to hold them together. The timing of the pump cam with the rotary valve was checked. The only repair found to be necessary in over a year of use has been the replacement of the aliquoting pump diaphragm using sheets of ordinary rubber dental dam. The moisture condensing in the meter was poured out the inlet tube every other day during intensive use.

Meter Methods.

The subjects require little instruction in the use of the equipment. To allay any anxiety about the use of the equipment the subjects wore the meter for 5-10 minutes at least once before any measurements were performed. There were rare complaints of dryness of the mouth in spite of the low relative humidity, 10-40%, frequently encountered in the atmosphere. The subjects were instructed in using the tongue to moisten the interior of the mouth if dryness occurred or to swallow frequently if excessive salivation occurred.

The aliquot bladder was always stored full of expired air in order to saturate it with carbon dioxide. Just before use the bladder was evacuated, closed off with a pinch clamp and then connected to the sample outlet of the meter. The meter was placed on the subject and the harness adjusted so

as to produce minimum restriction of the subject's movements. The subject put on the nose clip and inserted the mouthpiece, then breathed through the meter for several minutes. The fit of the mouthpiece and nose clip was checked to insure an air tight seal and comfort. The operation of the respiratory valve was checked for leaks. Subjects with a perforated ear drum require an ear plug to prevent loss of expired air. Oronasal masks with valves have been substituted for the respiratory valve and mouthpiece in a few situations. Initial temperature and volume readings were taken, recorded and checked by repeat readings. The position of the aliquot size selector knob was checked. The time of day was recorded for the barometer reading. As nearly simultaneously as possible, the pinch clamp was removed from the neck of the aliquot bladder, the meter was started to record volume and collect the aliquot, and the stop watch was started. To end the collection period the meter was turned off and the stop watch stopped. Final volume and temperature readings of the meters were made, recorded and checked. The neck of the aliquot bladder was clamped and the bladder removed to be sampled.

The meter was employed in two ways to measure energy expenditure, the partial method and the integral method (5). The partial method employs the collection of expired air during the physiological steady state at intensities of work not incurring an oxygen debt. Measurement is begun only after the subject has achieved a steady state, after at least 10 minutes sustained work. The integral method employs the collection of expired air from the beginning of an activity to its end and for from 5-10 minutes of standard sitting recovery position afterward. Measurement during the 5-10 minute recovery period permits the inclusion of any oxygen debt in the estimation of the cost of the task. In the event a large oxygen debt is anticipated a correspondingly longer recovery period may be employed. Only the integral method can be used when a steady state is not obtained either because of intermittent or irregular activity or because of work incurring an oxygen debt. In the calculation of the energy expenditure for the task, the previously determined energy equivalent of the recovery period in the standard sitting position for 5 or 10 minutes, or longer, is deducted from the total expenditure. By this method continuous measurement could be made for periods up to 31 minutes long with 662 liters total expiratory gas volume.

Using an oronasal face mask, changing aliquot bladders between breaths, and pooling and mixing the total aliquots under oil prior to sampling for analysis, continuous measurements have been made for periods as long as 186 minutes, with total ventilation of 2709 liters at meter temperature and total caloric expenditure of 401 calories.

GAS SAMPLES

Glass syringes served both to transport as well as to store gas samples (6). The 30 or 50 ml. syringes were lubricated with mineral oil and sealed by a Hoffman screw clamp on a short piece of butyl rubber tubing wired to the syringe tip. The butyl rubber tubing, 1/8" thick wall, inside diameter 3/16", was used because of its low permeability to gases.

Gas aliquots were transferred from the aliquot bladder to the glass syringes immediately after collection. The aliquot bladder was carefully kneaded to mix its contents, then the gas sample was transferred by means of a three-way Ayer stop cock to the syringe, taking three flushes of the syringe with 5-10 ml. of gas before the final sample was drawn. Duplicate syringe samples were routinely collected.

GAS ANALYSIS

Analysis of the gas samples for oxygen content was performed with the Pauling oxygen analyzer, A.O. Beckman model E-2, with porous diffusion plate protecting the test body (4). The analyzer was connected to a vacuum train of capillary glass tubing and small bore butyl rubber tubing so that the gas samples were introduced into the evacuated test cell of the analyzer and then equilibrated to atmospheric pressure for the analyzer reading (Figure IV). To prevent a sudden surge of gas damaging the test body of the analyzer upon admission of the sample to the evacuated train, a fine capillary narrowing was interposed in the train. To speed evacuation of the train between samples, the train to the vacuum pump included a by-pass around the fine capillary. In this train the total volume of gas needed to perform an analysis was about 11 ml. Generally, evacuation of the train is adequate to remove samples between analyses; flushing of the system was not necessary. Response time of the analyzer is about 55 seconds and the evacuation time is 50 seconds. The total time to perform each analysis is about 2½ minutes. Triplicate analyses can be performed on 50 ml. contained in syringes. The rate of analysis is 12 syringes per hour in duplicate or 24 syringes per hour for single analysis. An operator becomes proficient after about 6 hours instruction and experience. The oxygen analyzer was warmed up 45 minutes. It was then calibrated with oxygen-free water-pumped nitrogen at the zero setting and with outside air saturated with moisture at the scale setting of 20.93% oxygen. All gas samples for calibration and analysis were saturated with moisture at room temperature and were not dried before analysis. The calibration was performed twice during each working day and more often if the barometric pressure changed rapidly during the day. The operation of the oxygen analyzer was checked several times each week by either running duplicate analyses in both the analyzer and the Haldane gas analyzer or by checking the analysis of a known nitrogen-oxygen mixture. The instability of the base line of the oxygen analyzer potentiometer due to fluctuations in line voltage was eliminated by the use of an auxiliary electronic voltage regulator, Sorenson model 500-S

CALCULATIONS

The data for each energy cost determination were recorded on a special form (Figure V). Temperature of the gas was taken as the average of the initial and the final meter temperatures during each measurement. The minute pulmonary ventilation was calculated from a nomogram for reduction to standard temperature, pressure and dryness (6), and corrected for the calibration constant of the meter. The corrected minute pulmonary ventilation, oxygen concentration of expired air, and the proportion of protein calories in the diet were applied to the Weir formula to obtain the minute caloric

expenditure:

$$\text{Calories/minute} = \frac{1.0548 - 0.0504 O_e}{1 + 0.082 p} \times \text{L. pul. vent./min.}$$

where O_e is % oxygen in expired air and p is the decimal fraction of total dietary calories from protein (3). A table of oxygen concentrations and corresponding caloric equivalents for the pulmonary ventilation may be calculated and used in place of Weir's nomogram, if the protein content of diet is known and remains relatively constant.

EVALUATION OF METHODS

Collection of gas aliquot in sample bladder.

The use of the rubber bladders for the collection of the aliquot of gas entails two sources of error, the effect of diffusion of the gas across the bladder walls and the effect of the functional dead space of the bladders.

The effect of the diffusion of gases across the walls of the aliquot sample bladder was tested by comparing the composition of typical expired air before and after storage of various volumes for lengths of times equivalent to typical periods, collection time plus storage time. The volumes placed in the bladder were the average volume during collection, i.e. half of the final volume, so that the apparent effect was double the effect actually encountered in practice. Three bladders of the type furnished with the meter were tested. The data are summarized in Table I. All gas analyses for each bladder were performed in duplicate except where the bladder volume was 60 ml. The coefficient of diffusion calculated from these data is 0.0006 to 0.001 volume oxygen percent change per minute where:

$$\% \text{ oxygen concentration change} = \frac{\text{coefficient of diffusion} \times \text{total time in the bladder}}{\text{liter volume measured} \times \% \text{ aliquot fraction}}$$

$$\text{e.g. } 0.09\% = \frac{0.001 \times 10 \text{ minutes}}{60 \text{ Liters} \times 0.2\% \text{ aliquot}}$$

In this consideration the effect of various initial oxygen concentrations upon the diffusion gradient is disregarded. A change in oxygen concentration of 0.015% to 0.045% in the range of 16.00% leads to a negative error in the Weir factor, for calculating energy expenditure, of 0.3% (0.0007/0.2437) to 0.9% (0.0021/0.2437). The larger error appears when small volumes of gas are measured, i.e. during the study of basal or sitting metabolism. During activities of moderate work, 15 l. per minute ventilation, the error is of the order of 0.3%. For most purposes the error can be neglected, but should be individually evaluated where extreme accuracy is desired or where the diffusion characteristics of the aliquot bladder are not known.

The natural tendency of the rubber aliquot bladders to spring into a position of least distortion results in the evacuated bladders aspirating gas when the starting control is turned at the beginning of a measurement.

This functional dead space is important when the total aliquot volume is small, i.e. 150 ml. The volume of gas aspirated into the bag is 5-10 ml. for the type of bladder furnished with the meter but may be as high as 90 ml. for a bladder such as a large beach ball. The occurrence of this error has been unpredictable. The gas drawn into the bladder under these circumstances comes from the chamber of the sample pump or by leaks around the rotary valve of the sample pump. In the extreme situation of the bladder aspirating 6 ml. of outside air at 20.93% oxygen followed by the collection of a 150 ml. aliquot at 16% oxygen, the average composition in the aliquot bladder is 16.19% instead of 16.00% oxygen. Fortunately this situation does not occur if the meter is operated a few minutes before the measurement is begun, since in that case the bladder aspirates thoroughly mixed expired air either from the chamber of the aliquot pump or from the exhaust stream of the meter as it bathes the rotary valve mechanism. For this reason it is important that the meter be operated a few minutes before a measurement is started.

Storage of Gas Samples in Syringes.

The effect of prolonged storage of gas samples in the syringes was tested by filling ten syringes with gas of uniform composition. Five of these syringes were analyzed immediately and 72 hours later the remaining five of the syringes were analyzed. There was no difference in the oxygen content of the gas between the two series of syringes. Initial oxygen concentration was 16.20%. It is concluded from this that gas samples may be stored in syringes for reasonable periods of time without significant change in the composition of the gas. The efficiency of the syringe as a storage vessel is dependent upon intact seals of the Hoffman clamp on the butyl tubing, the butyl tubing upon the glass syringe tip, and the syringe plunger with the syringe cylinder. With constant use the mineral oil on the syringe plunger is gradually lost and the seal between plunger and cylinder may be broken. Hence, it is necessary that the syringes be kept adequately oiled. A satisfactory criterion for this is that the portion of the plunger in contact with the cylinder be transparent and not frosted in appearance.

Effect of Saturation of Gas Sample with Moisture.

Moist cool gases may be analyzed in the Pauling oxygen analyzer because the test cell is maintained at about 140° F to prevent condensation of moisture on the sensitive elements. However, the presence of water vapor decreases the absolute concentration of oxygen in the gas mixture. To avoid analytical variations due to different degrees of humidity, a constant water vapor effect is obtained by routinely saturating all gas samples for calibration and analysis at room temperature 70° F. The water-pumped nitrogen for calibration is saturated by delivery into a moistened syringe. The outside air used for calibration is saturated by drawing it over a moist surface. It is assumed that the samples of expired air are essentially saturated at body temperature and most certainly are saturated at the lower room temperature. Since moisture may be abstracted from gases by condensation if they are cooled, transferred to a dry container, and brought up to initial temperature again, the transfer of expired air from one container to another is always performed at room temperature or higher. A decrease in absolute humidity

equivalent to 15 mm. water vapor pressure due to partial drying or cooling of the gas sample increases the oxygen concentration by 1.02 (620/605) e.g. from 16.00% to 16.32% oxygen which is equivalent to 16 parts of .260 in the Weir calculation or 6% negative error in the caloric expenditure.

The problem of the effect of variable humidity in the gas samples may be avoided by regularly drying all gas samples. A small calibre column of granular indicating desiccant may be inserted in the vacuum train. However this increases both the analysis time, because of delay in drying the sample, and the sample volume required to fill the train. Samples may also be dried as they are transferred from the bladder to the syringe by drawing the gas through a small drying column after adequate flushing. The choice of solution of the problem of the humidity is dependent upon the experimental conditions.

Gas Analysis by Haldane Apparatus and Pauling Analyzer.

The accuracy of the Pauling oxygen analyzer was evaluated by comparison with the Haldane oxygen analysis on 14 different duplicate gas samples randomly selected over a period of 8 months. All Haldane analyses were performed in duplicate by one operator while the Pauling analyses were performed in duplicate by seven different operators. The Haldane apparatus was routinely checked with an outside air sample before any analyses were performed. The value of oxygen in expired air ranged from 14.60% to 16.88% with an average of 15.58%. The average oxygen concentration by the Haldane analysis was 0.0068% higher than by the Pauling analysis. This is not a statistically significant difference, $t = 0.234$.

The precision (S.D.) of the Pauling meter in a series of duplicate analyses on 74 syringes was 0.0098% oxygen. This is less than can be accurately interpolated on the Helipot scale of the oxygen analyzer. These results support the conclusion that there is no necessity to perform duplicate analyses upon each aliquot syringe. Comparison of the initial analysis on 74 pairs of duplicate syringes gave a standard error of 0.07% oxygen. This loss of precision between duplicate syringes and duplicate analyses on each syringe is a reflection of discrepancies in gas sampling and storage technique. In the series of 74 pairs of duplicate syringes there were three pairs which differed by more than 0.08% oxygen: 0.41%, 0.17% and 0.71%. In each case the duplicate analyses on each syringe agreed. This supports the conclusion that duplicate sample syringes should be taken on each gas volume, but that only one analysis need be performed upon each syringe. In the event re-analysis of each syringe confirms a discrepancy between syringes, the lowest of the two oxygen values is taken to be the true value, as the most likely cause of error is contamination of samples with outside air leading to falsely high oxygen values.

Gas Temperature.

The temperature of the gas as it passes through the meter is measured by a thermometer installed in the meter case. The bulb of the thermometer is shielded from outside radiations and is bathed by the expired air as it

passes from the meter. In a series of 51 determinations on diverse activities the average temperature of the meter at the beginning of the measurement was 26.6°C . and over an average of 11.3 minutes it rose an average of 0.8°C ., S.D. 1.27, to a final temperature of 27.4° . In another series of studies the temperature was observed from the beginning of use without a preliminary warm-up period. The initial temperature averaged 23.5°C . and rose an average of 1.2° in ten minutes to 24.7° . Of this total rise 0.5° , or 42%, occurred within the first two minutes and 1° or 83% of the total rise occurred in the first five minutes. The response of the thermometer is rapid since it always registers a temperature rise within the first minute of meter operation. However there is undoubtedly some lag between the attainment of temperature equilibrium by the meter mechanism and the thermometer due to their physical separation.

Consideration of the possible temperature fluctuations during a determination reveals two major types of sequences: The temperature rises either evenly throughout or at a diminishing rate or may even plateau; the temperature rises but then falls either to plateau or continues back toward the initial value. The average of the initial and final readings is valid only in the one case where the temperature rises evenly and proportionally to the gas flow throughout the determination. In all other cases the average will be falsely low particularly with the integral method where the temperature of the low ventilation during the recovery period may be unduly weighted. The oscillating fluctuations that might be encountered during extended integral type studies would tend to cancel each other out. Thus, although the temperature will fluctuate during the determinations it is manifestly impractical to follow the temperature profile and record the volumes to enable proper weighting for gas flow. As noted above the total change in temperature during a determination was usually not more than one degree centigrade which may then be considered the approximate maximum error, amounting to 0.3% error in the calculation of the gas volume and of the total caloric expenditure. The actual error would be less since, for convenience, the average of the initial and final temperature was used in all the calculations.

Barometric Pressure.

The barometric pressure influences the determinations in two ways: Through its effect upon the calculation of the gas volumes at standard conditions, and through its effect upon the calibration of the Pauling oxygen analyzer.

The barometer was read every hour. The values used for the calculation of the standard temperature and pressure, dry gas volumes were those closest to the time of the experiment. In a randomly selected series of 16 observations the average total change, regardless of sign, was 0.48 mm. Hg. and the average change was minus 0.38 mm. Hg. This average change was equivalent to a correction of $626.48/626.00$ or minus 0.07% in the gas volume factor. This is the order of magnitude of the error that might be anticipated in the corrected gas volume and in the caloric expenditure attributable to the variations of barometric pressure while determinations are being made. The

actual error would tend to be less since the pressure measured within 1/2 hour of the determination is used for the calculation.

The Pauling oxygen analyzer was generally calibrated at the beginning of the day's work, 8-9 a.m., and again just after lunch, 1 p.m. On 15 randomly selected days the average difference between the barometric pressure at 8-9 a.m. and noon, and between noon and 4 p.m. was minus 0.8 mm. Hg. This change in barometric pressure would affect the accuracy of the Pauling analyzer calibration in proportion to the absolute change, i.e. $626.8/626.0$ at the usual prevailing barometric pressure. This change of 0.13% operating upon the concentration of oxygen is equivalent to 0.02% oxygen at the usual concentration of 15% oxygen in expired air, and one part in 260, or plus 0.48% upon the caloric expenditure.

Comparison of the Müller-Franz Meter and the Douglas Bag in Measurement of Energy Expenditure.

Each Müller-Franz meter is furnished with a calibration factor by the manufacturer. In order to evaluate simultaneously the accuracy of the measurement of the respiratory gas volume and the reliability of the aliquoting pump of the meters, studies were undertaken to compare the meter and the Douglas bag technique of indirect calorimetry, utilizing the Pauling analyzer and the Weir calculation for both determinations. The accuracy of the volume measurement of the Müller-Franz meter was initially compared with a laboratory dry gas meter calibrated against a Tissot spirometer. Air was forced from a spirometer through a train consisting of the laboratory dry gas meter and the Müller-Franz meter. At continuous flow rates of about 35 and 70 liters per minute, the Müller-Franz meter registered 0.984 of the volume registered by the laboratory dry gas meter. This is not a valid test of the operation of the Müller-Franz meter, however, since human expiration consists of intermittent flows with instantaneous rates over the range of 0-300 liters per minute.

To calibrate the meter under the physiological conditions encountered in actual use, men were placed in a steady state of work at various intensities and their energy expenditure measured alternately with the Müller-Franz meter and the Douglas bag. The same mouthpiece valve and tubing were used in both collections. The ratio of the energy cost measured by the Douglas bag to that measured by the meter gave the calibration factor. All the subjects used in the calibration studies were previously experienced in wearing the meter. Calibration studies were performed at four levels of activity: Reclining, walking at 2.0 miles per hour, walking at 3.2 miles per hour, and walking at 4.5-4.8 miles per hour. The studies in the reclining state were made after the subjects had reclined at least 30 minutes. The walking studies were performed with the aid of a motor-driven treadmill to assure constant rate and conditions of walking. The subjects carried the meter continuously, but did not carry the Douglas bag. Each subject walked at the designated speed for 12-15 minutes preliminary to measurement in order to achieve a steady state. The meter was warmed up during the last 2-5 minutes of each preliminary period. The period of collection for each measurement was 10 minutes in the reclining state, 5 minutes for slow and moderate walking, and 2 minutes during fast walking. These calibration studies were carried out

at room temperatures of 70-72° F. and 50% relative humidity. The average of the initial and final meter temperature during calibration was 24.26° C. The data on the calibration of one meter are summarized in Tables II-V. These studies were conducted over a period of 17 days. All gas volumes are expressed at conditions of standard temperature and pressure and dry.

The minute volumes measured at meter temperatures and pressures ranged from 5.5 to 43.8 liters per minute. Pooling the calibration factor values from the several sets of comparisons, gives the grand average for meter #1 a calibration factor of 1.0559, S.D. 0.0645 and coefficient of variation of 6.11%. This applies only to the meter set for a 0.3% aliquot. The meter was not calibrated for an aliquot of 0.6% since preliminary studies showed that the calibration factor varied with the size of the aliquot and was more nearly unity with the 0.3% aliquot. Similarly the calibration factor for a second meter with 0.3% aliquot was 1.07575, S.D. 0.01 and the coefficient of variation of 0.92%.

There was no statistically significant difference between the calibration factor derived from studies of meter #1 at resting metabolism and at walking of 3.2 miles per hour; with 12 degrees of freedom, t equals 0.07. Thus the meter calibration and precision is independent of the ventilation and intensity of work over this range of workload.

The study of the relation of the calibration factor to time is summarized in Table VI. Meter #1 had been in use some months before the present calibration series began. From April, until the meter was adjusted in September, there was no significant change in the calibration. The September change was significant by the t test at 2% probability. Meter #2 had been used very little prior to May and can be considered to be new at that time. Its calibration showed a progressive change, significant at the 1% probability in June and 2% subsequently. The changes were significant always at either the 1 or 2% probability, but not at the 0.1% level. It may be concluded from this that the calibration of the meter does change with time, but that the change decreases as the meter is "broken in". The change is consistently in the direction of greater accuracy.

Adjustment of the mechanism and replacement of the aliquot pump diaphragms may change the calibration. During intensive use the calibration should be checked frequently, every 2-3 weeks using one level of activity, 3.2 mph walk. Limited rough handling of the meter does not appear to effect the calibration.

The effect of altitude upon the calibration factor of the meter was studied at two levels of activity; reclining, and exercising upon a bicycle ergometer (Table VI. Meter #1). These studies were performed in an altitude test chamber at 10,000 feet simulated altitude.* The calibration factor at

*The altitude chamber was used through the courtesy of the Physiological Training Unit of the 3415 USAF Hospital, Lowry Air Force Base, Denver, Colorado, Lt. George R. Beers, Physiologist.

ground level, 5000 feet, (620 mm. Hg. barometric pressure) was 1.0559 and the calibration factor at 10,000 feet altitude (525 mm. Hg. barometric pressure) was 1.03568. With 18 degrees of freedom there was no statistically significant difference between these two calibration factors, $t = .716$, so that changes in barometric pressure with altitude do not affect the accuracy of the meter.

Study of the effect of low temperatures upon the calibration factor of the meter has revealed the meter to become less accurate at lower temperatures. At a meter temperature of minus 27° C. in still air the calibration factor was 1.578. Currently efforts are being made to adapt the meter to use under these conditions.

Weir Calculations of Energy Expenditure.

The Weir calculation was compared with two conventional methods of calculating respiratory metabolism, that accounting for protein metabolism (7) or that ignoring protein metabolism by assigning 5 calories per liter O₂ consumed (6). As part of an energy balance study on five men a number of determinations of energy expenditure were performed by analyses of both oxygen and carbon dioxide (8). Throughout the study the men ate their regular dietary and continued their usual occupations and routine activities. During the actual balance phase of the study the protein intake was measured daily for two weeks. There were no significant changes during this period in body weight nor body composition. On the assumption that these data were representative of the period when the energy expenditure determinations were made, i.e. immediately before the balance phase, and that the men were in nitrogen balance, the average daily protein intake would be a measure of the protein metabolism and the protein contribution to the total metabolism (Table VII). For each energy determination the total oxygen consumption and the total carbon dioxide production were calculated using the method of the "true oxygen" and the "true carbon dioxide". The protein contribution to the total metabolism was calculated in terms of oxygen and carbon dioxide (Table VII) and deducted from the totals to give the non-protein metabolism (Table VIII). Using the non-protein RQ, the non-protein energy metabolism was calculated. The total energy metabolism was obtained by adding the non-protein calories to the protein calories (Table VIII, last column).

The short method of calculation based on 5 calories per liter of oxygen consumed, and the Weir formula employing only the concentration of oxygen in expired air and the minute volume of expired air, adjusted to a daily dietary protein intake of 10% of the total calories, were applied to the same raw data. The comparison of the methods of calculating energy metabolism is presented in Table IX. It is seen that the result with the Weir method is 101.2% and the short method 105.6% of the conventional method.

The theoretical partial regression equation of heat output on oxygen consumption, CO₂ production and urinary (dietary) nitrogen as derived by Weir is:

$$\text{Total Calories} = 3.941 \times \text{liters of oxygen} + 1.106 \times \text{liters of CO}_2 - 2.17 \times \text{grams of nitrogen.}$$

Applying this equation to the first four examples of Table IX and comparing the results to those of the conventional calculations gives, respectively, values of 1.44 calories per minute and 1.40 calories per minute, 2.45 and 2.40, 4.41 and 4.41, 2.07 and 2.04 with an over-all ratio of 1.0117 to 1.

This random series would indicate that the Weir formulation employing only measurement of oxygen concentration in expired air and the minute expiratory gas volume is in close agreement with the method calculating energy metabolism by oxygen consumption and carbon dioxide production corrected for protein metabolism. Further studies have been undertaken to confirm this impression (8).

The protein correction in the Weir formulation used in the examples is based upon the assumption that 10% of the total calories arise from protein metabolism. Actually the exact protein contribution may range as high as 15% in normal diets. The error introduced by this assumption has been evaluated by comparing the caloric equivalent per liter of expired air of various oxygen concentrations at three different levels of dietary protein, 10%, 12.5% and 15% in Table X. Comparing the equivalents by their ratios shows that the maximum error incurred by applying the 10% formula to a situation with 15% dietary protein results in the caloric equivalent being 0.36% too high. This error is essentially independent of the oxygen concentration of expired air at normally encountered values, 15 parts in 100,000 over 15 to 16.5% oxygen. If the formula for 12.5% protein, $\text{Cal/L} = 1.044 - 0.499 O_e$, is used the error is correspondingly less, 0.2%. Employment of the Weir formula adjusted to the men's individual protein intake (Table VII, Column 1) for the data in Table IX makes no significant change in the calorie expenditure.

The Effect of the Meter upon Normal Respiration.

Subjectively, the meter offered very slight resistance to expiration. The inventors cite a resistance of 8 mm. of water at a continuous flow of 20 liters per minute (3).

Any possible effect of the Müller-Franz meter upon respiration should be intensified at high rates of exchange. This effect could be revealed by a comparison of the meter values with the Douglas values of respiratory volume and expired oxygen concentration at two levels of activity, assuming the Douglas method to give normal values. Using the meter:Douglas ratio from the calibration data of meter #1, there was no significant difference between resting and 3.2 mph metabolism: $t = 0.277$ for expired oxygen and $t = 1.58$ for ventilation, both with 12 degrees of freedom (Tables II and IV). Therefore, there is no difference between the response of respiration to the meter and to the Douglas bag, but this does not exclude the possibility that both exert a similar effect upon respiration.

Cost of Wearing the Meter.

The amount of extra energy it costs to wear the meter is largely dependent upon the spatial motions of the meter. In standing and almost all

other activities the wearer does static work supporting the weight of the meter. When moving the body, the wearer must cause the acceleration and deceleration of the meter mass. In positional changes affecting the potential energy of the body, the meter weight must be raised and lowered. Studies were undertaken to evaluate the significance of some of these factors.

Since a large proportion of time is spent standing or walking slowly and since it was felt the position and weight of the meter might exaggerate the unsteadiness inherent in such a movement, the energy cost of walking at 2 mph was determined with and without the meter on the back. After walking 10 minutes on a motor driven treadmill three pairs of comparisons were made. The average cost without the meter was 2.922 Cal/min. and the average cost with the meter on the back was 2.829 Cal/min. The difference is not significant, $t = 0.4$ with 4 degrees of freedom.

The effect of the meter upon walking at a higher speed was determined, since here the acceleration and deceleration of the meter weight would be more prominent. After walking 10 minutes at 3.5 mph on a treadmill energy costs were measured in triplicate with and without the meter on the back. The average cost without the meter was 5.51 Cal/min. and the cost with the meter was 5.54 Cal/min. The difference is insignificant, $t = .245$. It may be concluded that for most activities the additional work entailed in carrying the meter was insignificant.

Activities in which the movements and positional changes of the upper torso are prominent would cost more with the meter on than without since the weight of the meter has to be moved. If such activities occur frequently studies should be made to evaluate the contribution of the meter to the total energy cost.

Total Error.

The errors of the method may be partially estimated by analysis of the error contributed by the various components of the techniques as discussed in the preceding paragraphs. The analysis is presented in Table XI. Some of the errors are routinely positive and others routinely negative. The range of maximal error estimated by summation of the effect of the error upon the caloric expenditure when all errors are exerting their negative effect is minus 13.88% and when all are exerting their positive effect is plus 1.48%. It is assumed the meter is calibrated frequently to avoid error in changing calibration factor. This consideration does not evaluate the error of the Weir formulation due to any possible error of the basic data from which it is derived.

DISCUSSION

Many of the practical difficulties characteristic of the use of the Douglas bag and Haldane gas analyzer for indirect calorimetry are overcome by the use of these newer techniques. The Müller-Franz meter can be readily applied over a wide range of energy expenditure, 1-9 Cal/min., with reasonable accuracy and convenience. The Pauling oxygen analyzer enables rapid accurate

gas analysis after a minimum of technician training with a precision comparable to the Haldane. Weir's simplified formulation of energy metabolism calculations obviates the need for carbon dioxide analyses and includes the effect of protein without extensive data upon protein metabolism.

The methods can be rendered totally portable if the electronic components are fixed on mechanical shock resistant mountings, a 2000 watt portable generator provides electricity, and compressed gases in small cylinders are used for calibration and verification of the gas analyzer. To date the methods have been applied to the measurement of energy expenditure in phases of paratrooper training, in hospital ward work, hospital clinic work, in load carrying, in daily living activities and in swimming.

These techniques while applicable to the determination of energy expenditure during short periods of time, minutes, may be used to estimate energy expenditure for longer periods, days, when applied in conjunction with time motion studies. The time motion study provides data upon the time distribution of activities, which in combination with knowledge of the energy cost of the activities, permits estimation of total energy expenditure during the period under investigation. Further study is indicated to determine the absolute accuracy of the methods when applied with time motion study to the estimation of extended energy expenditure.

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TABLE I

DIFFUSION OF GAS THROUGH ALIQUOT BLADDERS

<u>Bladder</u>	<u>Time</u> Minutes	<u>Bladder</u> Volume (ml)	<u>% O₂ Concentration</u>		
			Initial	Final	Av. Change
1	10	60	16.17	16.27	
2			16.17	16.24	+ 0.09%
3			16.17	16.26	
1	10	150	16.04	16.07	
2			15.90	15.93	+ 0.03%
3			15.88	15.91	
1	40	250	16.18	16.21	
2			16.19	16.23	+ 0.04%
1	60	600	16.64	16.67	
2			16.61	16.64	+ 0.03%
3			16.61	16.65	

TABLE II

CALIBRATION OF MÜLLER FRANZ METER #1 WITH 0.3% ALIQUOT AGAINST DOUGLAS BAG

Resting Metabolism						
DATE	SUBJECT	DOUGLAS BAG		MÜLLER FRANZ METER		CALIBRATION FACTOR Douglas Calories ÷ Müller Calories
		Ventilation L/min	% O ₂ Expired Air	Ventilation L/min	% O ₂ Expired Air	
7 Apr	In	5.04	15.77	4.79	15.90	1.20
		4.83	15.45	4.89	15.75	1.26
8 Apr	Ho	5.32	15.87	5.18	16.07	1.26
		5.41	16.08	5.46	16.41	1.23
		5.45	15.96	5.59	16.34	1.28
		4.55	15.71	4.56	15.76	1.18
14 Apr	In	3.98	15.33	4.03	15.71	1.05
		--	--	4.19	16.11	1.01
15 Apr	In	5.14	16.01	4.85	16.07	1.18
		5.05	16.16	5.03	16.23	1.18
15 Apr	In	6.14	16.16	4.66	16.20	1.10
		5.39	15.94	5.45	16.22	1.28
16 Apr	In	6.27	16.78	5.40	16.89	1.09
		5.60	16.65	5.67	16.94	1.13
		--	--	5.63	16.89	1.13

TABLE II (cont)

CALIBRATION OF MÜLLER FRANZ METER #1 WITH 0.3% ALIQUOT AGAINST DOUGLAS BAG

		Resting Metabolism					
DATE	SUBJECT	DOUGLAS BAG		MÜLLER FRANZ METER		CALIBRATION FACTOR	
		Ventilation L/min	% O ₂ Expired Air	Ventilation L/min	% O ₂ Expired Air	Cal/min	Douglas Calories + Muller Calories
16 Apr	In	6.41	16.44	5.92	16.76	1.23	0.9000
		5.67	16.47	7.91	16.44	1.77	
20 Apr	In	5.58	16.04	5.70	16.30	1.32	
		5.29	15.91	5.36	16.33	1.23	1.05426
		5.13	15.50	5.38	16.03	1.32	
21 Apr	In	5.05	15.71	5.88	16.34	1.35	
		5.05	15.79	5.83	16.09	1.41	0.96962
		4.55	15.61	4.94	16.11	1.19	
22 Apr	In	5.40	15.77	5.95	16.25	1.39	
		5.18	15.72	5.23	15.95	1.30	1.03807
		5.25	15.78	5.11	16.01	1.25	
Average							1.04911

TABLE III

CALIBRATION OF MÜLLER FRANZ METER #1 WITH 0.3% ALIQUOT AGAINST DOUGLAS BAG

Walking Treadmill 2.0 mph 0.0% Grade

DATE	SUBJECT	DOUGLAS BAG			MÜLLER FRANZ METER			CALIBRATION FACTOR	
		Ventilation L/min	% O ₂ Expired Air	Cal/min	Ventilation L/min	% O ₂ Expired Air	Cal/min	Douglas Calories	Müller Calories
5 Apr	Tr	14.91	15.60	3.97	11.44	15.45	3.13	1.15807	
		14.60	15.37	4.05	14.98	15.76	3.86		
		15.37	15.40	4.24	13.51	15.28	3.81		
		17.10	15.81	4.37	13.32	15.58	3.56		
7 Apr	Ho	11.86	15.41	3.27	13.60	16.16	3.24	1.04181	
		13.17	16.01	3.23	11.92	15.75	3.08		
		12.17	15.74	3.15	11.90	16.02	2.92		
		--	--	--	11.85	15.67	3.11		
7 Apr	Ho	12.04	15.61	3.20	11.85	15.74	3.07	1.036637	
		12.08	15.69	3.16	12.05	15.78	3.10		
		13.37	16.04	3.26	12.10	15.78	3.11		
		Average							

TABLE IV

CALIBRATION OF MULLER FRANZ PETER #1 WITH 0.3% ALIQUOT AGAINST DOUGLAS BAG

Walking Treadmill 3.2 mph 0.0% Grade

DATE	SUBJECT	DOUGLAS BAG			MULLER FRANZ METER			CALIBRATION FACTOR	
		Ventilation L/min	% O ₂ Expired Air	Cal/min	Ventilation L/min	% O ₂ Expired Air	Cal/min	Douglas Calories	Muller Calories
5 Apr	Tr	17.82	15.35	4.96	16.83	15.34	4.70	1.06468	
		18.56	15.35	5.17	16.96	15.30	4.77		
		19.36	15.78	4.98	16.89	15.36	4.69		
		17.99	15.39	4.97	17.01	15.39	4.70		
15 Apr	In	16.27	15.59	4.34	16.65	16.08	4.03	1.050206	
		15.69	15.41	4.32	15.80	15.72	4.11		
		--	--	--	15.70	15.53	4.23		
		16.50	15.83	4.20	17.87	15.96	4.43		
8 Apr	Ho	17.32	16.04	4.23	16.54	15.79	4.24	1.00467	
		18.02	16.03	4.41	16.85	16.00	4.15		
		18.38	16.17	4.37	18.76	16.45	4.19		
		--	--	--	17.29	15.82	4.41		
9 Apr	In	16.51	15.30	4.64	16.02	15.51	4.33	1.06556	
		16.72	15.77	4.72	15.96	15.38	4.42		
		16.81	15.36	4.67	16.32	15.49	4.43		
		16.75	15.35	4.66	15.88	15.41	4.36		
							Average	1.04628	

TABLE V

CALIBRATION OF MULLER FRANZ METER #1 WITH 0.3% ALIQUOT AGAINST DOUGLAS BAG

Walking Treadmill 4.5-4.8 mph 0.0% Grade

DATE	SUBJECT	DOUGLAS BAG			MULLER FRANZ METER			CALIBRATION FACTOR	
		Ventilation L/min	% O ₂ Expired Air	Cal/min	Ventilation L/min	% O ₂ Expired Air	Cal/min	Douglas Calories	Muller Calories
9 Apr	Ho	31.83	16.32	7.32	30.60	16.42	6.89	1.05202	
		29.68	16.04	7.24	29.77	16.25	6.95		
9 Apr	In	31.75	15.19	9.10	30.57	15.20	8.74	1.04706	
		32.77	15.26	9.27	30.98	15.23	8.81		
		33.97	15.23	9.66	31.63	15.09	9.22		
								<u><u>Average</u></u>	
								1.0495	

TABLE VI

SUMMARY OF MÜLLER FRANZ METER CALIBRATION

	<u>Date</u>	<u>Calibration Factor</u>	<u>Significance</u>
Meter No. 1	April 5-17	1.055 ± 0.065	
	May 17 *	1.047 ± 0.059	
	June 5	1.028 ± 0.017	
	August 10-12	1.027 ± 0.012	
	August 17 **	1.035 ± 0.009	
	September 4 *	1.066 ± 0.015	Aug.-Sept. t = 3.45 Sig. at 2%
Meter No. 2	May 11-13 *	1.075 ± 0.010	
	June 5	1.065 ± 0.002	May-June t = 10 Sig. at 1%
	August 13	1.049 ± 0.004	June-Aug. t = 4.08 Sig. at 2%
	September 13	1.044 ± 0.024	Aug-Sept. t = 3.8 Sig. at 2%
	October 8 *	1.029 ± 0.007	June-Oct. t = 5.6 Sig. at 1%
Meter No. 3	September 23-24	1.067 ± 0.028	Aug.-Oct. t = 4.03 Sig. at 2%

* Meter adjusted prior to calibration.

** Meter calibration performed at 10,000 feet altitude above sea level.

TABIE VII

CAICUIATION OF PROTEIN ENERGY METABOLISM

<u>SUBJECT</u>	Protein % of Total Calories	Daily Protein Intake gms.	Minute Protein Intake gms.	<u>PROTEIN METABOLISM</u>		
				Oxygen Consumption L/min	CO ₂ Production L/min	Cal/min
Fa	14.99	103.38	.0718	.0694	.0556	.2872
Fr	12.80	96.22	.0668	.0646	.0517	.2672
Ja	15.92	96.98	.0673	.0651	.0521	.2692
Pu	13.19	105.66	.0734	.0710	.0568	.2936
Vo	13.10	98.30	.0683	.0660	.0529	.2732

TABLE VIII

CONVENTIONAL CALCULATION OF ENERGY METABOLISM

SUBJECT	ACTIVITY	O ₂ CONSUMP. L/min.	NON PROTEIN O ₂ CONSUMP.	CO ₂ PROD.	NON PROTEIN CO ₂ PROD.	NON PROTEIN RQ	CAL/ LO ₂	NON PROTEIN CAL.	TOTAL CAL.
Fa	Sit	.3047	.2353	.2319	.1763	.749	4.738	1.115	1.402
Fa	Errand	.5115	.4421	.3981	.3425	.775	4.770	2.109	2.396
Fr	3.2 mph	.9175	.8529	.7725	.7208	.845	4.856	4.142	4.409
Fr	Chg. Dress.	.4347	.3701	.3427	.2910	.786	4.784	1.771	2.038
Fr	Play Piano	.4682	.4036	.4088	.3571	.885	4.905	1.980	2.247
Fr	Ward Work	.4118	.3472	.3184	.2667	.768	4.761	1.653	1.920
Fr	Get Up	.6381	.5735	.4870	.4353	.759	4.749	2.724	2.991
Ja	Sit	.2844	.2193	.2360	.1839	.839	4.848	1.037	1.306
Pu	Ping Pong	.6291	.5581	.4749	.4181	.749	4.738	2.644	2.938
Vo	Office Work	.4858	.4198	.3542	.3013	.718	4.698	1.972	2.245
Vo	Lab Work	.7654	.6994	.7400	.6871	.9824	5.025	3.514	3.787
Vo	Stand	.4616	.3956	.3622	.3093	.782	4.778	1.890	2.163
Vo	Walk	.6362	.5702	.4927	.4398	.771	4.765	2.717	2.990

TABLE IX

COMPARISON OF METHODS FOR THE CALCULATION
OF ENERGY METABOLISM

SUBJECT	ACTIVITY	% O ₂ CONTENT EXPIRED AIR	WEIR FACTOR	VENTILATION l./min	TOTAL CALORIES, WEIR METHOD	TOTAL CALORIES, CONVENTIONAL METHOD	TOTAL CALORIES, SHORT METHOD
Fa	Sit	16.21	.235	6.12	1.44	1.40	1.52
Fa	Errand	15.53	.269	9.11	2.45	2.40	2.56
Fr	3.2 mph	15.19	.286	15.42	4.41	4.41	4.59
Fr	Chg. Dress.	15.36	.278	7.45	2.07	2.04	2.17
Fr	Play Piano	16.10	.241	9.42	2.27	2.25	2.34
Fr	Ward Work	15.54	.269	7.27	1.96	1.92	2.06
Fr	Get Up	15.26	.283	10.68	3.02	2.99	3.19
Ja	Sit	16.28	.230	5.90	1.36	1.31	1.42
Pu	Ping Pong	15.81	.255	11.64	2.97	2.94	3.15
Vo	Office Work	14.95	.298	7.65	2.28	2.25	2.43
Vo	Lab Work	16.14	.239	15.88	3.80	3.79	3.83
Vo	Stand	15.51	.271	8.12	2.20	2.16	2.31
Av.					2.52	2.49	2.63
Proportion of Conventional method					101.2%	----	105.6%

TABLE X

WEIR CALORIC EQUIVALENT OF EXPIRED AIR AND PROTEIN METABOLISM

Protein Calories	10%	12.5%	15%	Ratio of Equivalents	
% Oxygen Expired Air O _E	Calories per Liter Expired Air			10/15	12.5/15
15	.29637	.29589	.29528	1.00369	1.00206
15.5	.27138	.27095	.27039	1.00366	1.00207
16.0	.24638	.24601	.24550	1.00358	1.00207
16.5	.22139	.22107	.22061	1.00353	1.00208

10% of total calories from protein

$$\text{Cal/I} = 1.046 - 0.050 \text{ O}_E$$

12.5% of total calories from protein

$$\text{Cal/L} = 1.044 - 0.0499 \text{ O}_E$$

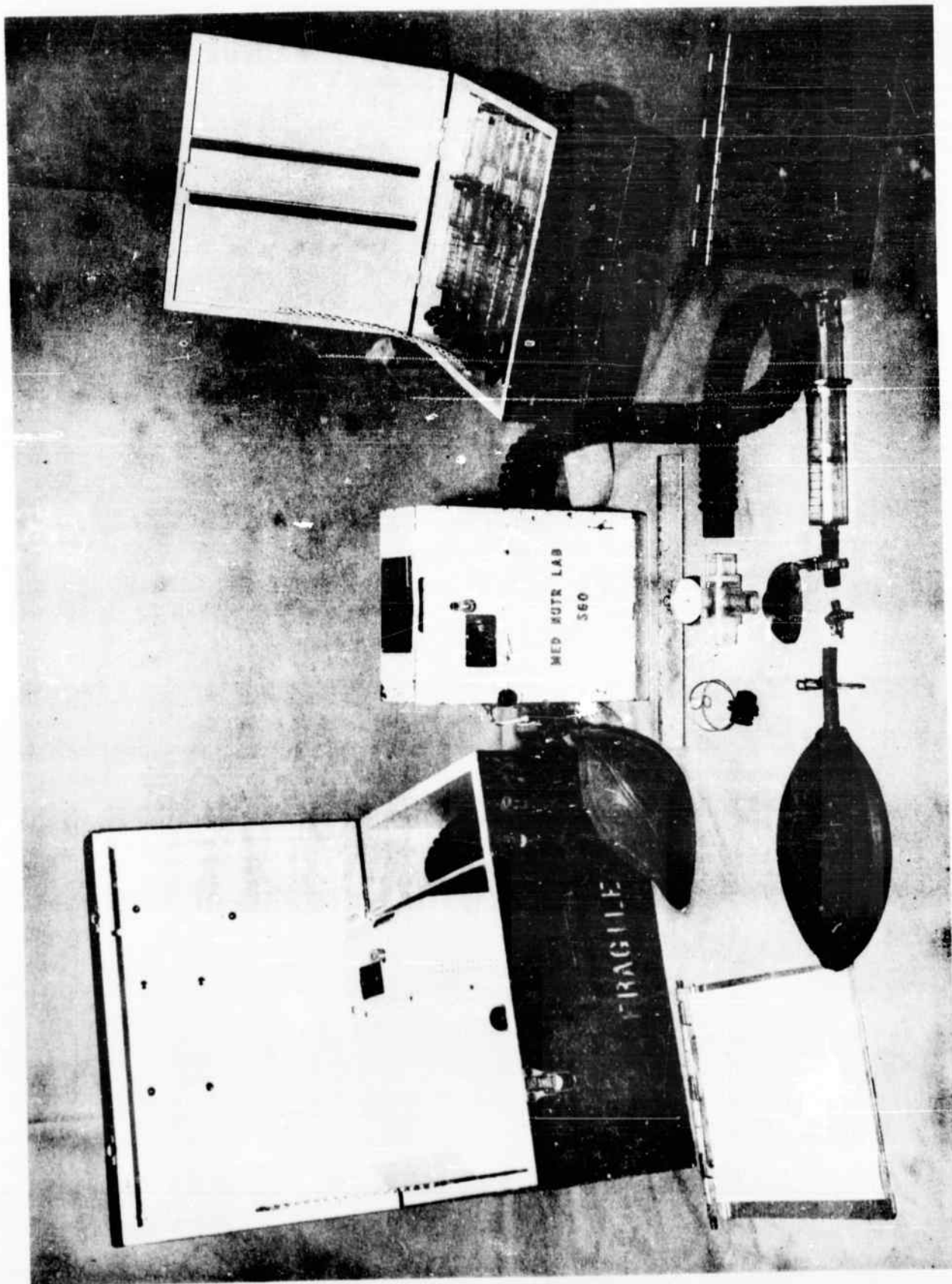
15% of total calories from protein

$$\text{Cal/L} = 1.042 - 0.0498 \text{ O}_E$$

TABIE XI

PARTIAL ANALYSIS OF ERROR OF THE METHOD

<u>Source of error</u>	<u>Manifest effect</u>	<u>Final effect on calories</u>
Diffusion through aliquot bladder	plus 0.015 to 0.045% O ₂	minus 0.3 to 0.9%
Decrease moisture in gas sample	plus 0.32% O ₂	minus 6.0%
Gas temperature at meter	1 degree C.	± 0.3%
Barometric pressure variation on meter gas volume	minus 0.38 mm Hg. partial press. O ₂	minus 0.06%
on Pauling calibration	minus 0.8 mm Hg. partial press. O ₂	plus 0.48%
Oxygen analysis	plus minus 0.14% O ₂ (2 x S.D. of 0.07% O ₂)	± 2.86%
Meter calibration	plus minus 0.04 (2 x S.D. of 0.02)	± 4.0%
Diet protein variation from Weir formula	10-15% calories from protein	± 0.2%
		Maximum negative error -13.88%
		Maximum positive error + 1.48%



GPO 835175

FIGURE I. M-F METER AND EQUIPMENT USED IN THE FIELD

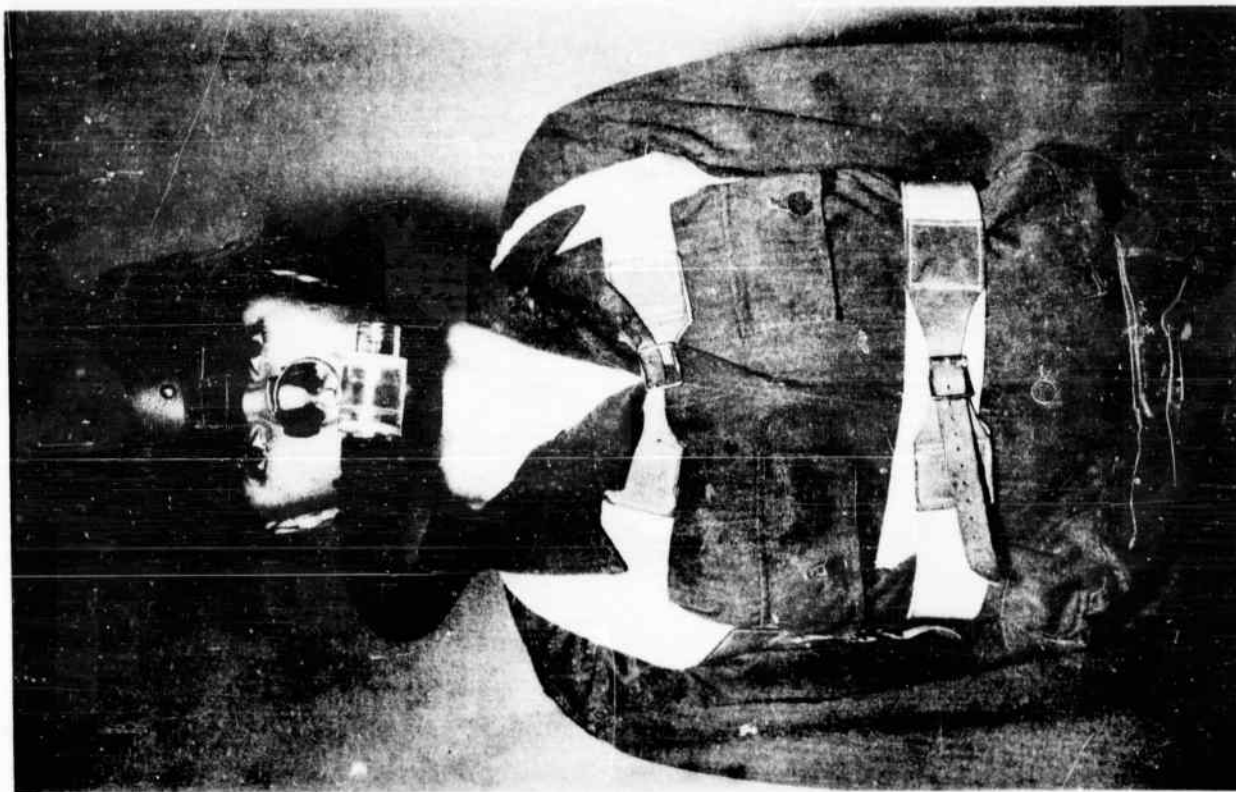


FIGURE II. ARRANGEMENT OF METER AND HARNESS. FRONT AND REAR VIEW



FIGURE III. ARRANGEMENT OF METER WHILE
CARRYING FULL FIELD PACK AND RIFLE

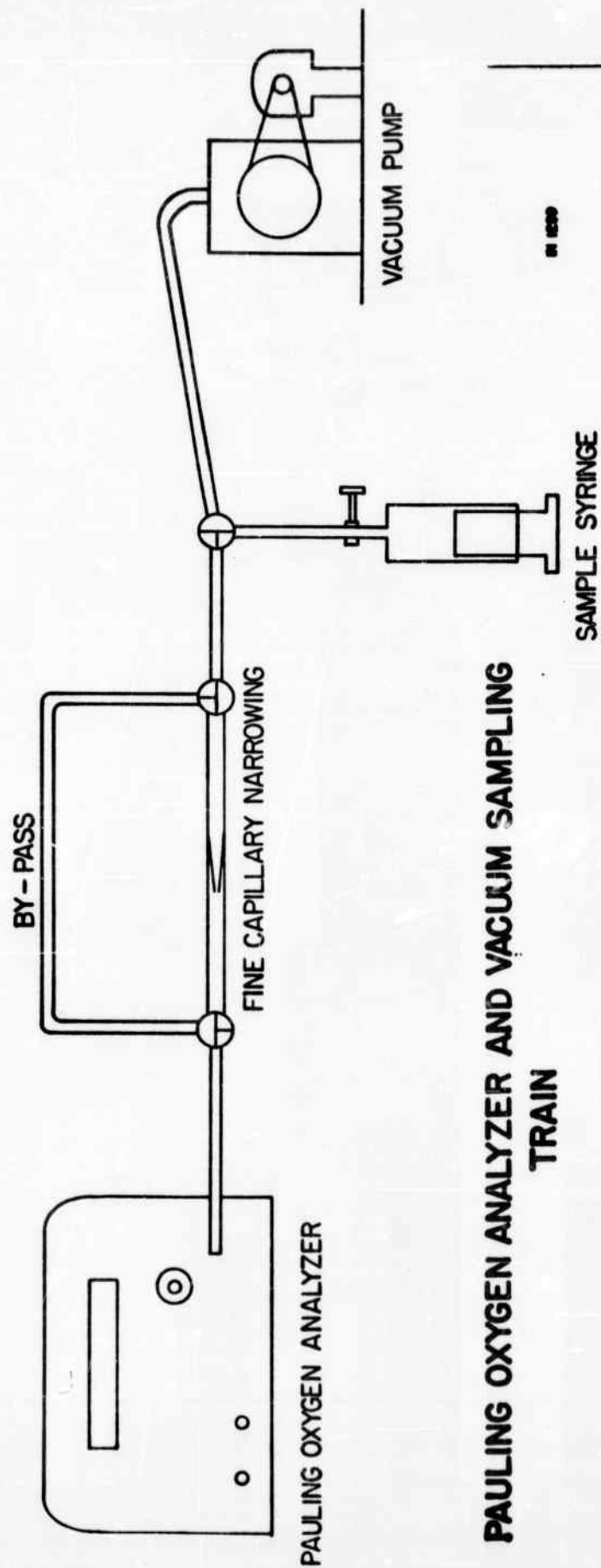


FIG. IV

FIGURE V

IN 1284

EXPERIMENTAL SERIES

EXPT 2960

DATE

NAME..... SERIAL NUMBER.....

M F RACE..... AGE..... HT..... WT.....

OCCUPATION

METER NO.....METER CONSTANT.....METER FRACTION.....%

FINAL.....L FINAL.....C

INITIAL.....L Temp. INITIAL.....C TIME..... TO.....

DIFF.....L AV.....C WARM UP PERIOD.....

CORR.....L BAROMETER.....MM WORK PERIOD.....

STPD VOL.....L STPD FACTOR..... RECOVERY PERIOD.....

CAL. TOT..... COLLECTION PERIOD.....

BASAL CAL..... SYRINGE

WORK CAL. TOT..... NO....., %O₂....., %CO₂....., CAL/L.....

WORK CAL/MIN..... NO....., %O₂....., %CO₂....., CAL/L.....

ACTIVITY ANALYSIS AND CONDITIONS

Field Exp Div Med Nutr Lab 9937 TU 11/8/54